PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark
Office, PCT
2011 South Clark Place Room
CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 09 April 2001 (09.04.01)	
International application No. PCT/EP00/07284	**Applicant's or agent's file reference** WO 21.0886
International filing date (day/month/year) 25 July 2000 (25.07.00)	**Priority date** (day/month/year) 05 August 1999 (05.08.99)
Applicant LEGENDRE, Emmanuel et al	

1. The designated Office is hereby notified of its election made:

   [X] in the demand filed with the International Preliminary Examining Authority on:

   23 February 2001 (23.02.01)

   [ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was

   [ ] was not

   made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland

Facsimile No.: (41-22) 740.14.35

Authorized officer

S. Mafla

Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION RELATING TO PRIORITY CLAIM

(PCT Rules 26bis.1 and 26bis.2 and Administrative Instructions, Sections 402 and 409)

To:

MENES, Catherine
Etudes & Productions Schlumberger
26, rue de la Cavée
B.P. 202
F-92142 Clamart Cedex
FRANCE

Date of mailing (day/month/year) 09 November 2000 (09.11.00)	
Applicant's or agent's file reference WO 21.0886	**IMPORTANT NOTIFICATION**
International application No. PCT/EP00/07284	International filing date (day/month/year) 25 July 2000 (25.07.00)
Applicant SCHLUMBERGER TECHNOLOGY B.V. et al	

The applicant is hereby **notified** of the following in respect of the priority claim(s) made in the international application.

1. [X] **Correction of priority claim.** In accordance with the applicant's notice received on: 27 September 2000 (27.09.00), the following priority claim has been corrected to read as follows:

FR 05 August 1999 (05.08.99) 99/10178

- [ ] even though the indication of the number of the earlier application is missing.
- [ ] even though the following indication in the priority claim is not the same as the corresponding indication appearing in the priority document:

2. [ ] **Addition of priority claim.** In accordance with the applicant's notice received on: , the following priority claim has been added:

- [ ] even though the indication of the number of the earlier application is missing.
- [ ] even though the following indication in the priority claim is not the same as the corresponding indication appearing in the priority document:

3. [ ] As a **result of the correction and/or addition** of (a) priority claim(s) under items 1 and/or 2, the (earliest) priority date is:

4. [ ] **Priority claim considered not to have been made.**

- [ ] The applicant failed to respond to the Invitation under Rule 26bis.2(a) (Form PCT/IB/316) within the prescribed time limit.
- [ ] The applicant's notice was received after the expiration of the prescribed time limit under Rule 26bis.1(a).
- [ ] The applicant's notice failed to correct the priority claim so as to comply with the requirements of Rule 4.10.

The applicant may, before the technical preparations for international publication have been completed and subject to the payment of a fee, request the International Bureau to publish, together with the international application, information concerning the priority claim. See Rule 26bis.2(c) and the PCT Applicant's Guide, Volume I, Annex B2(IB).

5. [ ] In case where **multiple priorities** have been claimed, the above item(s) relate to the following priority claim(s):

6. A copy of this notification has been sent to the receiving Office and

- [X] to the International Searching Authority (where the international search report has not yet been issued).
- [X] the designated Offices (which have already been notified of the receipt of the record copy).

The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland

Facsimile No. (41-22) 740.14.35

Authorized officer
Lazar Joseph Panakal

Telephone No. (41-22) 338.83.38

WO 01/11391
PCT/EP00/07284

PATENT COOPERATION TREATY

23 FEV. 2001

From the INTERNATIONAL BUREAU

PCT

NOTICE INFORMING THE APPLICANT OF THE COMMUNICATION OF THE INTERNATIONAL APPLICATION TO THE DESIGNATED OFFICES

(PCT Rule 47.1(c), first sentence)

T :
MENES, Catherin
Etudes & Productions Schlumberger
26, rue de la Cavée
B.P. 202
F-92142 Clamart Cedex
FRANCE

MH 23/2/01

Date of mailing (day/month/year)	
15 February 2001 (15.02.01)	
Applicant's or agent's file reference WO 21.0886	**IMPORTANT NOTICE**
International application No. PCT/EP00/07284	**International filing date** (day/month/year) 25 July 2000 (25.07.00)
Priority date (day/month/year) 05 August 1999 (05.08.99)	
Applicant SCHLUMBERGER TECHNOLOGY B.V. et al	

1. Notice is hereby given that the International Bureau has communicated, as provided in Article 20, the international application to the following designated Offices on the date indicated above as the date of mailing of this Notice:
   AU,KP,KR,US

   In accordance with Rule 47.1(c), third sentence, those Offices will accept the present Notice as conclusive evidence that the communication of the international application has duly taken place on the date of mailing indicated above and no copy of the international application is required to be furnished by the applicant to the designated Office(s).

2. The following designated Offices have waived the requirement for such a communication at this time:
   AE,AL,AM,AP,AT,AZ,BA,BB,BG,BR,BY,CA,CH,CN,CR,CU,CZ,DE,DK,DM,EA,EE,EP,ES,FI,GB,GD,
   GE,GH,GM,HR,HU,ID,IL,IN,IS,JP,KE,KG,KZ,LC,LK,LR,LS,LT,LU,LV,MA,MD,MG,MK,MN,MW,MX,
   NO,NZ,OA,PL,PT,RO,RU,SD,SE,SG,SI,SK,SL,TJ,TM,TR,TT,TZ,UA,UG,UZ,VN,YU,ZA,ZW
   The communication will be made to those Offices only upon their request. Furthermore, those Offices do not require the applicant to furnish a copy of the international application (Rule 49.1(a-bis)).

3. Enclosed with this Notice is a copy of the international application as published by the International Bureau on
   15 February 2001 (15.02.01) under No. WO 01/11391

REMINDER REGARDING CHAPTER II (Article 31(2)(a) and Rule 54.2)

If the applicant wishes to postpone entry into the national phase until 30 months (or later in some Offices) from the priority date, **a demand for international preliminary examination** must be filed with the competent International Preliminary Examining Authority before the expiration of 19 months from the priority date.

It is the applicant's sole responsibility to monitor the 19-month time limit.

Note that only an applicant who is a national or resident of a PCT Contracting State which is bound by Chapter II has the right to file a demand for international preliminary examination.

REMINDER REGARDING ENTRY INTO THE NATIONAL PHASE (Article 22 or 39(1))

If the applicant wishes to proceed with the international application in the **national phase**, he must, within 20 months or 30 months, or later in some Offices, perform the acts referred to therein before each designated or elected Office.

For further important information on the time limits and acts to be performed for entering the national phase, see the Annex to Form PCT/IB/301 (Notification of Receipt of Record Copy) and Volume II of the PCT Applicant's Guide.

The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland

Facsimile No. (41-22) 740.14.35

Authorized officer
J. Zahra

Telephone No. (41-22) 338.83.38

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	FOR FURTHER ACTION	see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
WO 21.0886		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/EP 00/07284	25/07/2000	05/08/1999
Applicant		
SCHLUMBERGER TECHNOLOGY B.V.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 2 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

a. With regard to the **language,** the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

[ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

[ ] contained in the international application in written form.

[ ] filed together with the international application in computer readable form.

[ ] furnished subsequently to this Authority in written form.

[ ] furnished subsequently to this Authority in computer readble form.

[ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

[ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

[X] the text is approved as submitted by the applicant.

[ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract,**

[X] the text is approved as submitted by the applicant.

[ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 2

[ ] as suggested by the applicant.

[X] because the applicant failed to suggest a figure.

[ ] because this figure better characterizes the invention.

[ ] None of the figures.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 00/07284

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01V3/38

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 930 519 A (SCHLUMBERGER SERVICES PETROL ;SCHLUMBERGER TECHNOLOGY BV (NL); SCH) 21 July 1999 (1999-07-21) page 5, line 26 - line 47	1,4,6,14
A	US 5 867 806 A (JACKSON CHARLES E ET AL) 2 February 1999 (1999-02-02) column 4, line 49 -column 5, line 14	1-3
A	US 4 916 616 A (FREEDMAN ROBERT ET AL) 10 April 1990 (1990-04-10) column 10, line 17 - line 35	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 November 2000	27/11/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Häusser, T

3

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/EP 00/07284

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0930519 A	21-07-1999	US 6047240 A	04-04-2000
		NO 990183 A	19-07-1999
US 5867806 A	02-02-1999	CA 2248253 A	18-09-1997
		EP 0886794 A	30-12-1998
		WO 9734168 A	18-09-1997
US 4916616 A	10-04-1990	NONE	

PATENT COOPERATION TREATY

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

HYDEN, Martin
ETUDES & PRODUCTIONS SCHLUMBERGER
26, rue de la Cavée
B.P. 202
F-92142 Clamart Cedex
FRANCE

19 AVR. 2001
MH 14.4.01

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Rule 71.1)

Date of mailing *(day/month/year)*	17.04.2001
Applicant's or agent's file reference WO 21.0886	IMPORTANT NOTIFICATION

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/EP00/07284	25/07/2000	05/08/1999

Applicant
SCHLUMBERGER TECHNOLOGY B.V. et al.

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. **REMINDER**

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

Name and mailing address of the IPEA/	Authorized officer
European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Marnell, J Tel.+49 89 2399-2557

Form PCT/IPEA/416 (July 1992)

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
WO 21.0886		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/EP00/07284	25/07/2000	05/08/1999
International Patent Classification (IPC) or national classification and IPC G01V3/38		
Applicant SCHLUMBERGER TECHNOLOGY B.V. et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 4 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☐ Certain defects in the international application
   - VIII ☒ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
23/02/2001	17.04.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Trique, M Telephone No. +49 89 2399 2223

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/EP00/07284

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:
Description, pages:

1-9 as originally filed

Claims, No.:

1-14 as originally filed

Drawings, sheets:

1/2-2/2 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-14
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-14
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-14
	No:	Claims	

2. Citations and explanations
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

Re Item V

Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability;

1. ***Technical field***

   The invention disclosed in claims 1 to 14 discloses a method of determining physical parameters of geological formations on the basis of resistivity borehole measurements.

2. ***State of the art***

   Standard prior art, mentionned on p.1-3 of the present application, relates to inversion methods for evaluating resistivity of geological formations on the basis of borehole measurements, taking into account e.g. the shoulder bed effect, as stated in US-A-5 867 806 or the invasion effect, as stated in EP-A-0 930 519.

3. ***Novelty - Art. 33(2) PCT***

   The subject-matter of the independent method claim 1 differs from the prior art in that a quasi-Newton method with homogeneous pseudo-parameters is used for the data inversion. Consequently, the subject-matter of claim 1 is new.

4. ***Inventive step - Art. 33(3) PCT***

   The use of these new technical features allows to improve the stability and accuracy of models provided by the inversion of the borehole measurements. Indeed, the inverse problem is solved in a linear way. Moreover, the shoulder bed effect and the invasion effect are treated together. Therefore, the instability of the method is reduced and its accuracy is improved.

5. ***Dependent claims***

   The dependent claims 2 to 14 disclose preferred embodiments of the invention described in claim 1. Consequently, their subject-matter also involves an inventive step (Art. 33(3) PCT).

Re Item VIII

C rtain obs rvations on th int rnational application

6. The symbols used in claim 12 to 14 have to be defined (Art. 6 PCT, Guidelines CIII-4.2).

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 February 2001 (15.02.2001)

PCT

(10) International Publication Number
WO 01/11391 A1

(51) International Patent Classification[7]: G01V 3/38

(21) International Application Number: PCT/EP00/07284

(22) International Filing Date: 25 July 2000 (25.07.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
99/10178 5 August 1999 (05.08.1999) FR

(71) Applicant *(for all designated States except CA, FR, GB, US)*: **SCHLUMBERGER TECHNOLOGY B.V.** [NL/NL]; Parkstraat 83-89, NL-2514 JG The Hague (NL).

(71) Applicant *(for FR only)*: **SERVICES PETROLIERS SCHLUMBERGER** [FR/FR]; 42, rue Saint Dominique, F-75007 Paris Cedex (FR).

(71) Applicant *(for CA only)*: **SCHLUMBERGER CANADA LIMITED** [CA/CA]; 24th floor, Monenco Place, 801 6th Avenue S.W., Calgary, Alberta T2P 3W2 (CA).

(71) Applicant *(for GB only)*: **SCHLUMBERGER HOLDINGS LIMITED** [—/—]; Craigmuir Chambers, Road Town, P.O. Box 71, Tortola (VG).

(72) Inventors; and

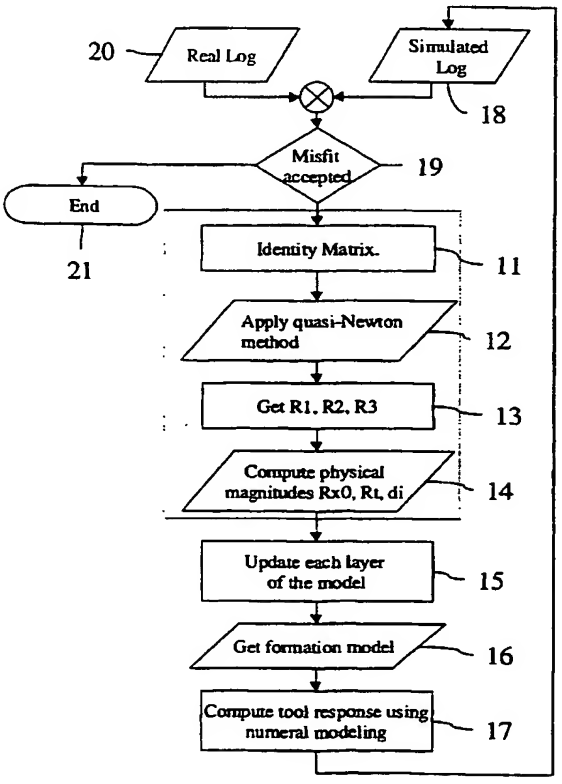
(75) Inventors/Applicants *(for US only)*: **LEGENDRE, Emmanuel** [FR/FR]; 18, Grande Rue, F-92310 Sèvres (FR). **SMITS, Jan** [NL/US]; Schlumberger Oilfield Services, 110 Schlumberger Drive 110-4, Sugar Land, TX 77478 (US).

(74) Agent: **MENES, Catherine**; Etudes & Productions Schlumberger, 26, rue de la Cavée, B.P. 202, F-92142 Clamart Cedex (FR).

(81) Designated States *(national)*: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK,

[Continued on next page]

(54) Title: A METHOD OF DETERMINING PARAMETERS OF FORMATIONS THROUGH WHICH A BOREHOLE PASSES



(57) Abstract: The invention relates to a method of determining parameters of formations through which a borehole passes, on the basis of a resistivity log (20) recorded in said borehole by means of a measuring and recording tool, the method comprising the steps consisting in determining said formation parameters by a parameter inversion method so as to obtain a model of the formations; calculating the response of said tool to said model; using a comparison criterion for comparing said calculated response with said recorded log; and performing at least one new iteration if said comparison criterion is not satisfied; the method being characterized by the fact that the invention is performed by a quasi-Newton method implemented on pseudo-parameters that are homogeneous and that are determined from said formation parameters.

WO 01/11391 A1

DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) **Designated States** *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

A METHOD OF DETERMINING PARAMETERS OF FORMATIONS THROUGH WHICH A BOREHOLE PASSES

The present invention relates to a method of determining parameters of formations through which a borehole passes, and more particularly to such a method of determining parameters on the basis of a resistivity log recorded in said borehole by means of a measuring and recording tool, said method comprising the steps consisting in:

- determining said formation parameters by a parameter inversion method so as to obtain a model of the formations;
- calculating the response of said tool to said model;
- using a comparison criterion for comparing said calculated response with said recorded log; and
- performing at least one new iteration if said comparison criterion is not satisfied.

Such methods are known. In general, they are implemented after a first stage of initializing parameters.

It is well known to make resistivity logs in boreholes by means of tools designed to measure the resistivity of the formations through which the borehole passes by establishing galvanic currents or eddy currents in the formations around the tool. Such tools give a set of resistivity values at each of the depths at which measurements are performed, the values applying to various distances from the axis of the borehole.

The relationship between the resistivity measurements performed in this way and the actual characteristics of the formations through which the borehole passes are typically affected by three types of effect:

a) the hole effect due to the presence of the borehole, which is generally filled with a drilling mud that is much more conductive than the formations;

b) the shoulder bed effect due to the presence of generally heterogeneous formations above and below the zone being investigated, which formations can perfectly well have greater conductivity or greater resistivity than the formations level with the apparatus (it should be observed that the shoulder bed effect can be considerable even if the sonde is completely contained within a homogeneous bed surrounded by formations of different resistivities); and

c) the invasion effect due to the presence of drilling mud filtrate in the vicinity of the borehole, where the filtrate has replaced some of the fluids that were initially present in the formations.

To a first approximation, the invaded zone is represented by a region extending between the borehole and a cylinder of diameter d_i that is coaxial with the borehole and that has radially uniform resistivity R_{x0}, and beyond which a virgin zone of resistivity R_t is to be found. That model has three unknowns: R_t, R_{x0}, and d_i, which is why at least three measurements having different radial investigation depths are recorded simultaneously so as to be able to determine the three unknowns.

The problem thus consists in determining at each depth a set of geometrical and electrical parameters, for example in this case the invasion diameter d_i and the resistivity R_{x0} of the invaded zone and the resistivity R_t of the virgin zones, on the basis of a set of resistivity measurements performed at depths that are separated by a given measurement pitch, the resistivities measured at each depth each being characteristic of the resistivity of the formation at a certain distance from the axis of the borehole.

Various methods are known that are capable of resolving that problem. Such methods are essentially of three types.

A first type of known method makes use of deconvolution filters. That approach assumes that the observed signal is the result of convolution between the real distribution of resistivities and a filter which represents the response of the tool to a resistivity distribution (or a conductivity distribution if the convolution is performed on the basis of a conductivity distribution). The method of interpretation then consists in deconvoluting the observed log by means of a known filter so as to discover the resistivity distribution. This step corresponds to correcting the initial data for shoulder bed effects.

This step is preceded or followed by a radial correction step seeking to correct for the results of the invasion effect.

The convolution filter can also be estimated by calculating the response of the tool to a formation possessing a resistivity distribution close to reality, which correpsonds to local linearization of the filter.

Methods of that type are limited by the fact that the corrections performed therein for the shoulder bed effect and for the invasion effect are assumed to be independent whereas in reality they cannot, in general, be separated.

Another type of known method consists in partitioning the formation into cells.

Attempts are then made to obtain an image of the formation in terms of resistivity. The formation is partitioned into cells (usually in rectangle following the borehole axis and perpendicular to that axis), and a resistivity value is defined for each cell. A calculation algorithm is then used, e.g. using finite elements, finite differences, or a neural network, to calculate the response of the tool to the formations modelled in

this way, so as to determine whether the assumed resistivity distribution explains the apparent resistivity.

The horizontal boundaries of the cells can be determined by a segmentation algorithm and the vertical boundaries are often fixed by the user. In general, the use of cells of large size leads to poor definition and thus to a poor approximation to reality, while the use of small cells can lead to instability which requires constraints to be fixed concerning the suddenness with which resistivity can vary, and such constraints deform the solution.

The unknowns of the inverse problem which are electrical unknowns only, are in this case the resistivities of the various cells. These resistivities present a large number of degrees of freedom, that can lead to the above-mentioned instability. As mentioned above, one way of resolving such instability problems consists in imposing constraints, however such constraints suffer from the drawback of falsifying the solution.

The problem is easier to resolve when the number of resistivities describing a layer or bed is relatively small. However, under such circumstances, the model of the formation is less accurate. A bed split into a small number of radial zonesdoes not accurately approximate the more realistic piston-profile model (R_{x0}, d_i, and R_t). This model insufficiency introduces a systematic bias into the inversion process.

A third type of known method consists in performing parametric local inversion. The general idea on which this approach is based is to use Newton's method to invert all of the unknown parameters describing the formation, such as the positions of the bed boundaries, and the values of d_i, R_{x0}, and R_t, i.e. in this case the geometrical and resistivity parameters. In order to obtain a large enough number of observable magnitudes, several reading of the tool near the area inverted can be used. A criterion – for instance a quadratic criterion - for evaluating error between observable magnitudes and reconstituted reading is minimized.

The advantage of that method is its flexibility. A wide variety of formation models can be used and there is a large amount of freedom in selecting input measurements.

However, because of the generality of that approach, the inverse problem is often highly non-linear. Consequently, only local inversion can be performed and accurate gradients must be estimated, which is extremely expensive in terms of computation time.

Furthermore, when the method is used on real logging data, instabilities are observed which are the result of the local nature of the inversion.

The present invention seeks to mitigate those drawbacks.

To this end, the invention provides a method of determining parameters of formations through which a borehole passes, on the basis of a resistivity log recorded in said borehole by means of a measuring and recording tool, the method comprising the steps consisting in determining said formation parameters by a parameter inversion method so as to obtain a model of the formations; calculating the response of said tool to said model; using a comparison criterion for comparing said calculated response with said recorded log; and performing at least one new iteration if said comparison criterion is not satisfied; said method being characterized by the fact that the step of determining said parameters from log data is performed by a quasi-Newton method; and said quasi-Newton method is implemented on pseudo-parameters that are homogeneous and that are determined from said formation parameters.

The method of the invention assumes that the boundaries between the layers (beds) are known.

In addition, any method known in the prior art is used for reconstituting the response of the tool to a given description of the formation (direct model).

For each bed, a bed model can be selected as being the most realistic. One particular bed model is a partition of the bed into various radial zones each of which possesses contact resistivity. In each bed, some of the parameters can be selected as being the unknowns of the inverse problem. Both resistivity and the positions of the radial interfaces constitute possible unknowns.

A certain number of "observables" are associated with each bed. An "observable" is a measurement made by the tool which is considered to be a function of the unknowns of the bed. For example, if the tool gives two measurements at each depth, the two measurements obtained close to the middle of the bed can be selected as being a function of two parameters of the bed model.

The observables can be the result of the same kind of measurement, but taken at different depths or with the tool in different positions. The rule for selecting observables depends on the tool and on the model that is to be inverted. The generality of the method of the invention makes inversion possible with a wide selection of observables.

Consequently, the invention is based on local methods of parametric inversion. Nevertheless, optimization is now performed that is not local, i.e. that takes place simultaneously over all of the layers.

The hole effect is obviated by assuming that the resistivity of the mud is known and also that the diameter of the borehole is known. In addition, the positions of the horizontal boundaries between the beds are known, e.g. from zero crossings of the second derivative of conductivity.

It is also assumed that the resistivity values at certain radial depths are known, e.g. the resistivities R_{LLs} and R_{LLd}, or other radial distributions of resistivity.

The unknowns at each depth are R_{x0}, R_t, and d_i.

If it is desired to determine specifically R_{x0}, then it is necessary to know the microresistivity, assuming that the measured values are R_{LLs} and R_{LLd}.

In any event, it is necessary in theory for the number of unknowns to be smaller than the number of observables. In practice, the method of the invention requires that the number of unknowns be equal to the number of observables. When the number of observables is greater than the number of unknowns, either no account is taken of some of the observables, or else combinations of observables are taken as unknowns.

The invention thus consists essentially in:

- firstly applying a quasi-Newton method to the problem of parametric inversion; and
- secondly improving convergence in a quasi-Newton method which is generally affected by combining geometrical parameters such as d_i and electrical parameters such as R_{x0} and R_t, by using combinations of such geometrical and electrical parameters as the unknowns, e.g. combinations that all consist in pseudo-electrical magnitudes, and in particular pseudo-resistivities.

Consequently, two transformations are generally performed when implementing the invention.

A first transformation is generally performed in the observables space so as to reduce the number of observables to the number of unknowns. This is necessary in order to be able to apply the inversion algorithm which assumes that the number of observables is equal to the number of unknowns.

The second transformation is performed in the unknowns space to obtain a set of unknowns that are homogeneous, in particular that are electrical, on the basis of unknowns that are not homogeneous, e.g. unknowns that are geometrical and unknowns that are electrical.

A particular implementation of the invention is described below by way of non-limiting example and with reference to the accompanying diagrammatic drawings, in which:

· Figure 1 is an overall flow chart of a method of the invention; and

· Figure 2 is a flow chart of an iteration of the calculation algorithm.

As shown in Figure 1, implementation of the method of the invention begins by a step 1 of measuring various physical magnitudes of the formation from inside a borehole. At each measurement level, the number of magnitudes measured in this way

must be not less than the number of parameters for which it is desired to obtain a value at each level.

By way of example, in the common case where the parameters that it is desired to determine are the resistivity values R_{x0} and R_t, and also the invasion distance d_i, making a total of three parameters, at least three magnitudes will be measured at each step.

By way of example, it is possible to measure the magnitudes R_{LLs} and R_{LLd} by means of a tool known as a Dual Laterolog (Schlumberger registered trademark) and to measure R_{x0} directly by means of a device known as an MSFL (Schlumberger trademark for "micro spherically focused log"). In another implementation of this step of the method, it is possible to measure the resistivities R_{LA1}, ..., R_{LA5} obtained by means of a device known as an HRLA (Schlumberger trademark for: "high resolution laterolog array"), which correspond to formation resistivities as measured at increasing distances from the axis of the borehole.

Following step 2 consists in determining the locations of the beds or layers whose parameters are to be determined. The locations of the beds can be determined automatically by means of a segmentation algorithm of known type, e.g. based on looking for points of inflection in the apparent conductivity values.

During this step, a first initialization value is given to each parameter.

Following step 3 consists in selecting the appropriate number of "observable" magnitudes. Remaining in the context where it is desired that R_{x0}, R_t, and d_i should be determined, the observables used will be the three measurements obtained by means of the dual laterolog and the MSFL, in the first case.

In the second case where measurements are made using the HRLA, one or two of the values R_{LA1}, ..., R_{LA5} can be eliminated and/or three observables can be obtained by combining these values, in particular by combining them in linear manner.

During following step 4, a value is given to each observable for each determined layer, as mentioned above.

It will be observed that more measurement steps are available than there are layers since it is necessary in particular to have at least three measurement steps in order to be able to determine a point of inflection.

For this purpose, it is possible to interpolate the measurements performed within a layer so as to obtain the value of each of the observables in the middle of the layer.

It is also possible to give each layer the values of the observables as measured at the measurement point that its closest to the middle of the layer.

The following step 5 consists in determining the looked-for parameters.

Mathematically, the problem is thus posed as follows.

This problem is the inverse of the direct problem in which it is desired to determine the response of the measurement tools, the observables of the problem of the invention, from the actual parameters of the formation, i.e. the unknowns in the problem of the invention.

We use the notation:

$f(U)=O$ for the direct problem; and

$U=f^{-1}(O)$ for the problem of the invention, i.e. the inverse of the direct problem.

The direct problem can be resolved, i.e. the system of non-linear equations f_i can be evaluated as a function of the layer model and of previously selected observables. By way of example, when the physical characteristics under consideration are resistivities, the layer model consists in defining how the resistivity of the terrain varies as a function of distance from the axis of the borehole, or indeed the R_{x0}, R_t, and d_i model.

To solve the inverse problem, it is necessary to use an iterative method, i.e. to determine a stream of values U_1, U_2, ..., U_∞ tending towards the solution $U_{solution}$, such that:

$$f(U_{solution}) = O_{observed}$$

In conventional methods, a term $U+$ of the above stream is obtained from the current term U_C using the following equation:

(1) $$U_+ = U_C - (\nabla f)^{-1} * [f(U_C) - O_{observed}]$$

where ∇f is the Jacobian of the function $f(U)$.

It is recalled that the Jacobian of the function f is defined as follows:

If $f: \mathfrak{R}^N \rightarrow \mathfrak{R}^N$

then $\nabla f: \mathfrak{R}^{NXN} \rightarrow \mathfrak{R}^{NXN}$

with $(\nabla f)_{i,j} = \dfrac{\partial f_i}{\partial u_j}$

It can thus be seen that a large number of evaluations of the function f is required to estimate the N□N matrix, given that the system of equations can typically have 1000 observables and 1000 unknowns.

According to the invention, instead of using Newton's method in which, on each iteration, a new vector U is estimated and a new Jacobian is calculated, a quasi-Newton method is used in which both the vector U and the Jacobian are estimated at each step. If the current estimate of the Jacobian is B_C, then equation (1) is replaced by:

(2) $$U_+ = U_C - B_c^{-1} * [f(U_C) - O_{observed}]$$

A new estimate of the Jacobian can be obtained on each iteration, for example, using the Broyden method as described at pages 113 to 131 of "Iterative method for linear and non-linear equations" by C.T. Kelley published by Society for Industrial and Applied Mathematics.

More precisely, the matrix B_+^{-1} at the following step is obtained from the current matrix B_c^{-1} using the following equation:

(3) $$B_+^{-1} = B_c^{-1} * \left(I + \frac{\left[f(U_c) - O_{observed} \right] * s^T}{s^T * s} \right)$$

where I is the identity matrix and where $s = U_+ - U_C$.

With this method, it is therefore no longer necessary to know the Jacobian.

Nevertheless, to ensure that the stream of B_n^{-1} converges quickly, the initial data is preconditioned so as to be homogeneous. In the present case, this is achieved not by using the variables R_{x0}, R_t, and d_i, which are not homogeneous, given the presence of d_i, but by using the resistivities R_{x0} and R_t, together with the pseudo-resistivity R_a as defined by:

(4) $$\begin{cases} R_a = \alpha * R_{x0} + (1 - \alpha) * R_i \\ \alpha = \dfrac{d_{imax} - d_i}{d_{imax} - d_{imin}} \end{cases}$$

where d_{imax} and d_{imin} are parameters fixed so as to correspond to maximum and minimum acceptable values for d_i.

Figure 2 is a complete flow chart for one interaction.

For example, the starting point is an identity matrix, and at 11, an iteration of the above-described quasi-Newton method is applied to obtain pseudo-resistivities R_1, R_2, and R_3 for each layer, as shown as 12.

The pseudo-resistivities R_1, R_2 and R_3 are then transformed at 13 into physical magnitudes 14: R_{x0}, R_t, and d_i.

It is then possible at 15 to update each layer of the model of the formation so as to obtain a formation model 16 which is updated in terms of R_{x0}, R_t and d_i.

The response of the tool to the formation 16 is then calculated at 17 in conventional manner, e.g. by a finite element method, so as to obtain a simulated log 18.

In step 19, the simulated log is compared with a real log 20. If the difference between the simulated log and the real log satisfies a predetermined criterion, the iteration terminates at 21. Otherwise, a new iteration is performed.

CLAIMS

1. A method of determining parameters of formations through which a borehole passes, on the basis of a resistivity log (20) recorded in said borehole by means of a measuring and recording tool, the method comprising the steps consisting in:

- determining said formation parameters by a parameter inversion method (11) so as to obtain a model of the formations;
- calculating the response of said tool to said model;
- using a comparison criterion for comparing said calculated response with said recorded log; and
- performing at least one new iteration if said comparison criterion is not satisfied;

said method being characterized by the fact that:

- said parameter inversion is performed using a quasi-Newton method; and
- said quasi-Newton method is implemented on pseudo-parameters (12) that are homogeneous and that are determined from said formation parameters.

2/ A method according to claim 1, including a step of determining the boundaries between geological beds, prior to implementing said quasi-Newton method.

3/ A method according to claim 2, in which the bed boundaries are determined on the basis of points of inflection in the log data.

4/ A method according to any one of claims 1 to 3, comprising a step of selecting a bed model for each geological layer, prior to implementing said quasi-Newton method.

5/ A method according to claim 4, in which the bed model is constituted by parameters concerning distance from the borehole axis so as to define radial zones about said axis, and a resistivity parameter within each radial zone as defined in this way.

6/ A method according to any one of claims 1 to 5, including a step of selecting observable magnitudes.

7/ A method according to claim 6, in which selecting the observable magnitudes includes defining a combination of data items from the log.

8/ A method according to claims 4 and 6 together, comprising a step of giving each observable a value for each geological bed.

9/ A method according to claim 8, in which the step of giving each observable a value for each geological bed comprises interpolating, within each layer, values of the observable as determined within each bed.

10/ A method according to claim 8, in which each observable is given a value for each geological bed by giving said observable the value it possesses at the measurement point closest to the middle of the bed.

11/ A method according to any one of claims 1 to 10, in which the step of determining said parameters from log data by a quasi-Newton method is performed by estimating the Jacobian of the problem by Broyden's method.

12/ A method according to any one of claims 1 to 11, in which the log used is the R_{LLs} and R_{LLd} log.

13/ A method according to any one of claims 1 to 11, in which the log used is the R_{LA1}, ..., R_{LA5} log.

14/ The use of the method according to any one of claims 1 to 13 in determining the parameters R_t, R_{x0}, and d_i.

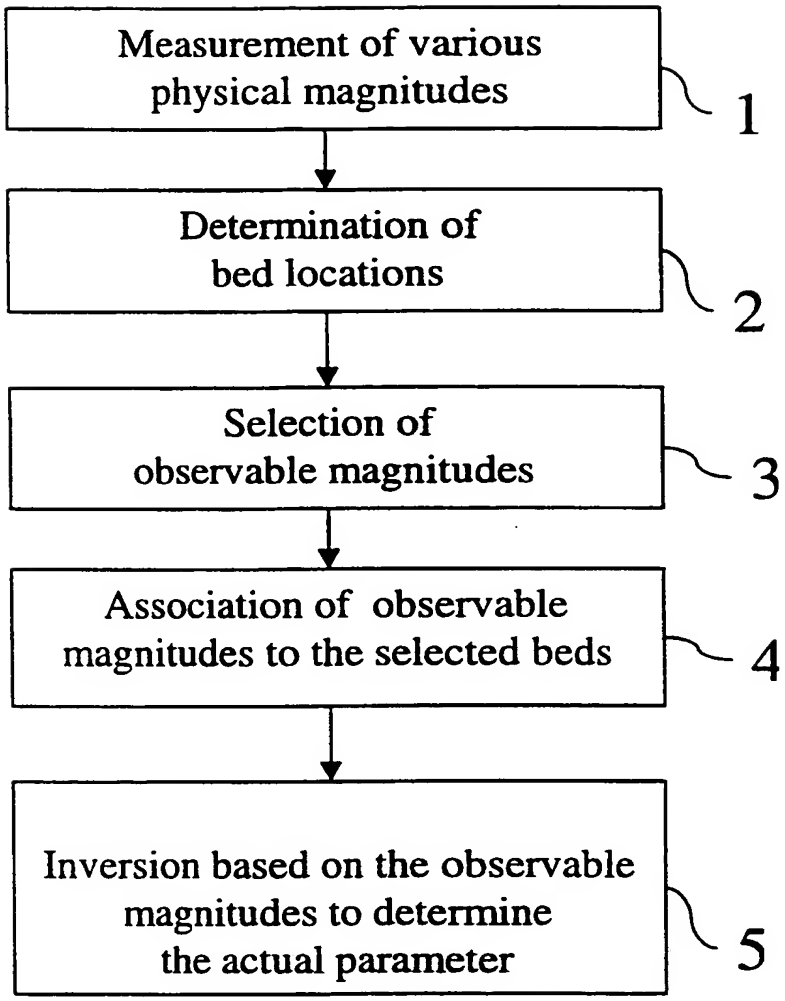
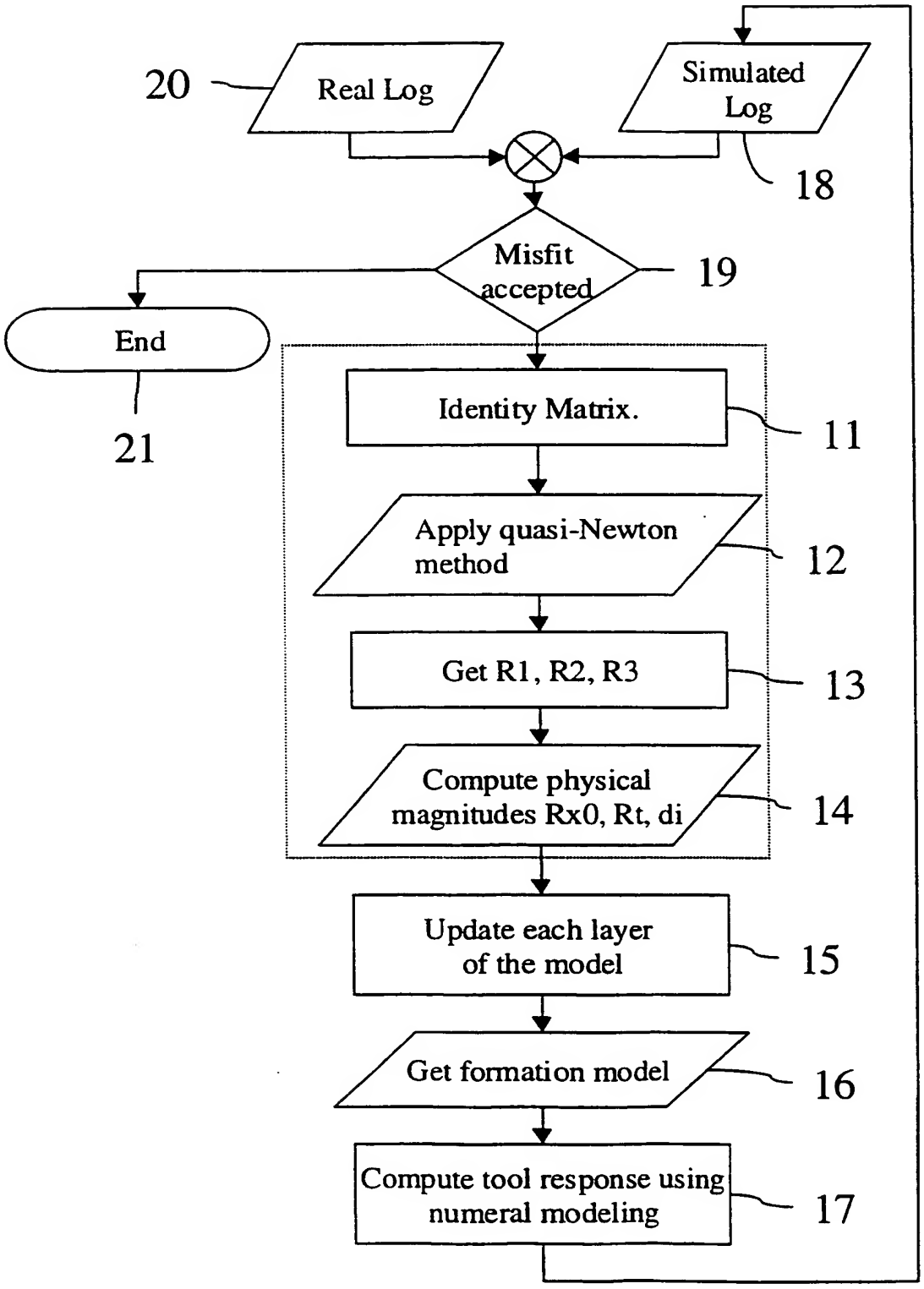

Measurement of various physical magnitudes
1
Determination of bed locations
2
Selection of observable magnitudes
3
Association of observable magnitudes to the selected beds
4
Inversion based on the observable magnitudes to determine the actual parameter
5

FIGURE 1

FIGURE 2


20
Real Log
Simulated Log
18
Misfit accepted
19
End
21
Identity Matrix.
11
Apply quasi-Newton method
12
Get R1, R2, R3
13
Compute physical magnitudes Rx0, Rt, di
14
Update each layer of the model
15
Get formation model
16
Compute tool response using numeral modeling
17

INTERNATIONAL SEARCH REPORT

Interna al Application No
PCT/EP 00/07284

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01V3/38

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 930 519 A (SCHLUMBERGER SERVICES PETROL ;SCHLUMBERGER TECHNOLOGY BV (NL); SCH) 21 July 1999 (1999-07-21) page 5, line 26 - line 47	1,4,6,14
A	US 5 867 806 A (JACKSON CHARLES E ET AL) 2 February 1999 (1999-02-02) column 4, line 49 -column 5, line 14	1-3
A	US 4 916 616 A (FREEDMAN ROBERT ET AL) 10 April 1990 (1990-04-10) column 10, line 17 - line 35	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 November 2000	27/11/2000

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

Interna al Application No
PCT/EP 00/07284

Pat nt document cited in search report		Publication date	Patent family member(s)		Publication date
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